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Friability of Spray-Applied Fireproofing and Thermal Insulations: Field Evaluation of Prototype Test Devices

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National Bureau of Standards became the National Institute of Standards and Technology on August 23, 1988, when the Omnibus Trade and Competitiveness Act was signed. NIST retains all NBS functions. Its new programs will encourage improved use of technology by U.S. industry.

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ABSTRACT

This report describes results of the third and final phase of a study conducted for the General Services Administration (GSA) to develop a field test method to measure the friability of spray-applied fireproofing and thermal insulation materials. Field tests were conducted on 17 fibrous and two cementitious spray-applied materials to assess surface and bulk compression/shear, indentation, abrasion, and impact properties. The tests were performed using prototype devices developed in an earlier phase of the study. As expected, the field specimens displayed varying response to dislodgment or indentation in the tests. The field tests confirmed that the goal of the study had been achieved.

In the case of the surface compression/shear test, it was found that, where comparable replicate specimens were available, variability in the test results was, in some cases, 30 percent or greater. It was also found that the use of the indentation test was limited by specimen thickness, and consequently, it was recommended that this test be omitted from testing of material friability.

It was also recommended that the surface and bulk compression-shear, abrasion, and impact tests all be used by GSA in a procedure for assessing the friable nature of spray-applied fireproofings. Assessments of friability can be performed using a systematic procedure for conducting tests as outlined in a flow diagram. A third recommendation was that, if testing is to be conducted with the intent to monitor changes in the friability of the specimens, appropriate statistical procedures should be developed.

Key words: abrasion; asbestos-containing materials; compression; field evaluation; fireproofing; friability; impact; indentation; mechanical tests; shear; spray-applied; test devices; test methods; thermal insulations

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1. INTRODUCTION

This report describes results of the third and final phase of a study to develop a field test method to measure the friability of spray-applied fireproofing and thermal insulation materials. It includes the results of field tests conducted using prototype mechanical devices specifically devised for field testing. The three-phase study was conducted at the request of the General Services Administration (GSA) to have an objective field method for assessing friability of spray-applied asbestos-containing materials for use in abatement programs and in monitoring changes in friability over time.

Phase 1 included the development of the technical bases for the field test method for assessing friability. Included in the scope of Phase 1 was the development of a conceptual model for determining a level of friability using mechanical tests, as well as the development of prototype devices for conducting the tests. The results of Phase 1 were described in a report entitled, "Friability of Spray-Applied Fireproofing and Thermal Insulation: the Basis for a Field Test Method" [1].

Phase 2 was undertaken to evaluate, in laboratory tests, the performance of the prototype devices in distinguishing different levels of friability of spray-applied fireproofing and thermal insulation materials. No field testing was performed. The results of Phase 2 were described in a report entitled, "Friability of Spray-Applied Fireproofing and Thermal Insulation: Laboratory Evaluation of Prototype Test Devices" [2].

1.1 Background

Many of the Nation's public buildings under GSA maintenance and operation were constructed in the era when spray-on asbestos-containing materials were extensively used as fireproofing and thermal insulation. In these buildings, GSA has assessed the condition of the asbestos-containing material, monitors changes in its condition over time, and has implemented a management and control program.

For purposes of asbestos control, a friable asbestos-containing material is "any material containing more than 1 percent asbestos . . . that hand pressure can crumble, pulverize, or reduce to powder when dry" [3]. Consistent with this definition, GSA [4], as well as other Federal agencies such as the Environmental Protection Agency (EPA) [3,5] and the Navy [6], have assessed the friability of in-place asbestos-containing materials from subjective and poorly defined actions using the hand. These actions may involve motions such as rubbing (abrasion), poking (indentation), and pinching or squeezing (compression/shear) [1]. If such actions dislodged the material from place or produced a residue, the material was considered to have some degree of friability. Algorithms, as discussed in the Phase 1 report [1], have been developed, and used in the past, to evaluate the potential hazard of asbestos-containing materials being released from spray-applied fireproofings. In particular, GSA used its algorithm as a means for obtaining a relative index of the risk potential associated with asbestos-containing materials in buildings under its responsibility [4]. The procedures in the

algorithms used in the past included classifying the level of friability as high, moderate, or low, based on the results of the subjective hand tests.

In recent years, the use of algorithm procedures for assessing levels of friability has greatly decreased [2]. Buildings under GSA responsibility have undergone assessments of sprayed-on fireproofings using algorithm-based procedures. GSA now has placed emphasis on a need to have available an objective field method for assessing friability for use in abatement programs and in monitoring changes in friability over time.

Although algorithms are currently used less than in the past for friability assessments, subjective methods involving hand actions such as rubbing the spray-applied material are still employed to classify friability. Because of the importance of having an objective ranking of the condition of the asbestos-containing materials in its buildings, GSA proposed that the friability test procedure using the hand should be replaced with an objective, quantitative procedure. Thus, GSA requested the National Institute of Standards and Technology[1] (NIST) to develop a field test procedure for assessing and monitoring the friability of spray-applied asbestos-containing materials.

This report presents the third phase of the study. The approach taken in developing a field test was to provide mechanical

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[1]formerly, National Bureau of Standards (NBS).

devices that could dislodge in-place spray-applied materials, indent them, or produce a residue on the device during testing (see Section 4). The mechanical devices would impart controlled actions and forces on the material somewhat akin to those generated by hand by field inspectors [2].

The approach suggested in this study for the field test method for assessing the friability of a spray-applied fireproofing or thermal insulation is empirical [2]. It was undertaken in response to a need for GSA to have available a field test method that is not subjective. Ultimately, what is needed is to relate the results of the measurements using the prototype devices to the probability of releasing fibers from the sample into the air. Also, it may be useful to consider whether an indicator or property other than friability would be useful for characterizing the potential of the spray-on material to release fibers [1]. Such properties might include cohesive/adhesive strength of the material and fracture mechanics characteristics such as the energy involved in fracturing or deforming the material.

1.2 Objective and Scope of the Study

The overall objective of the three-phase study is to develop a field test method to measure the friability of spray-applied fireproofing and thermal insulation materials. The level of friability has been associated with the potential of various types of spray-applied fireproofing and thermal insulations containing asbestos fibers to release materials into the building environment [7]. The objective of Phase 3 was to evaluate, in

field tests, the performance of the prototype devices in distinguishing levels of friability of different spray-applied fireproofing and thermal insulation materials.

The scope of Phase 3 was limited to field testing of the prototype devices using in-place spray-applied fireproofings. Tests were conducted in buildings in the greater Washington, DC-Baltimore, MD area. With one exception, all test materials contained asbestos. GSA personnel assisted in making arrangements for the field tests. Information on whether the test materials contained asbestos was provided by building personnel responsible for asbestos-control programs. No tests of the percent or type of asbestos in the test specimens were conducted, because such testing was beyond the scope of the study.

2. PROTOTYPE TEST DEVICES FOR ASSESSMENT OF FRIABILITY

As previously indicated, the development of the prototype devices for assessing friability and their use in controlled laboratory tests have been reported [1,2]. Appendix A presents previously published photographs of the prototype test devices for the convenience of readers who do not have available the Phase 2 report [2].

Five tests have been proposed as candidates for assessing the friability of spray-applied fireproofings and thermal insulation: surface compression/shear, bulk compression/shear, indentation, abrasion, and impact [1,2]. It was suggested in the Phase 2 report [2] that the tests be applied following the flow diagram given in Figure 1. The intent of the flow diagram is to provide a sequence for conducting the friability tests and recording the data which may be used by GSA in ways such as comparing results for a series of buildings (e.g., establishing abatement priorities), or monitoring changes in a material for a given installation over time. The sequence, given in Figure 1, was based on algorithm procedures for classifying spray-applied materials as having a high, moderate, or low level of friability. Thus, in following the flow diagram in Figure 1, it is expected that materials relatively prone to dislodging would be identified early in the sequence using the compression/shear tests, whereas those having increased resistance to dislodging would be subjected to further testing to consider damage by processes such as indentation, abrasion, or impact.

In using the flow diagram for conducting field assessments of friability of a spray-applied fireproofing or thermal insulation, it is anticipated that tests will be conducted sequentially until a positive result is obtained (i.e., a "yes" is produced). However, in the Phase 3 field study, for purposes of evaluating the devices, all five tests were generally conducted on each of the test specimens.

3. EXPERIMENTAL

3.1 Test Specimens

For purposes of the field tests, a test specimen was designated as a section of in-place spray-applied material whose area was limited to that on which the series of friability tests using the prototype devices were conducted. Consistent with this designation, a given room (or test site) would include more than one test specimen, if the series of friability tests were conducted at more than one location in the room (e.g., wall versus ceiling).

Table 1 summarizes the descriptions of the spray-applied fireproofing specimens. Nineteen specimens were included in the field tests. They were located in seven buildings. In three of the buildings, the tests were conducted in two rooms (sites). Seventeen specimens were fibrous and two were cementitious. The fibrous specimens did not have any surface coating, except Specimen No. 19 which had been painted. The cementitious specimens were on ceilings which had apparently been painted.

Eighteen of the 19 spray-applied specimens were examined manually by a GSA industrial hygienist, experienced in asbestos assessment procedures, according to the algorithm-based descriptors for judging the friability of asbestos-containing materials (Tables 2 & 3). Friability levels were assigned to the specimens based on the industrial hygienist's judgment, and are given in Table 1. Since the judgment was made using a subjective procedure, it was

possible that other investigators might have assigned other friability levels.

With two exceptions, the fibrous specimens were judged to have high or moderate friability. In the other two cases, a clear-cut classification was not made. One fibrous material (Specimen No. 5) was considered as having moderate-to-high friability, and another (Specimen No. 19) was judged as having low-to-moderate friability. This latter specimen was that which had the painted surface; this may have contributed to its assigned low-to-moderate friability rating.

One cementitious specimen was judged to have low friability, while the other was described as not friable (Table 1). One specimen was not assigned a friability level because the GSA industrial hygienist, who made the assignments, was not able to be present during the field testing.

In conducting the field tests, no samples of the spray-applied asbestos-containing material were removed from the test sites. Consequently, measurements of physical characteristics such as density were not made.

3.2 Test Procedures Using the Prototype Devices

The procedures for using the prototype devices in the field were the same as those performed in the laboratory program (Phase 2) and have been previously described [2]. The variable parameters associated with each of the test devices and values of these

parameters selected for the field tests are given in Table 4. These values were the same as those used in the laboratory tests.

During planning of the field test program, it was intended to perform the five proposed friability tests using each of the prototype devices on all specimens. The reason was to investigate the response of each device to materials having varying levels of friability. However, practical considerations such as the size of the test area, specimen damage, and location of the specimen in the building, precluded conducting all of the tests on some of the 19 specimens. Table 5 lists the tests conducted on each specimen.

Analysis of the results was performed with the assistance of the NIST statistician who participated in the first two phases of the study. Data were recorded in a computer file and analyzed using a statistical graphics program called "DATAPLOT" [8].

3.2.1 <u>"Pass/Fail Points" Using the Compression/Shear Devices</u>. As described in the Phase 2 report [2], the surface and bulk compression/shear tests, using the torque screwdriver, were conducted as "pass/fail" tests [2]. At the beginning of a test, a torque level for the torque screwdriver device was arbitrarily selected. The disk of the device (e.g., Figure A1) was placed against the surface of the specimen, and the handle of the screwdriver was manually rotated. For the pre-set torque level, the specimen at the test location was designated as having "passed" if it resisted the level of applied torque without

pieces dislodging. Conversely, for the pre-set torque level, the specimen at the location of the test was designated as having "failed" if pieces were dislodged at a torque less than or equal to the setting.

The torque setting on the screwdriver was increased or decreased in successive tests until a "pass/fail point" was experimentally determined for the specimen. The pass/fail point was associated with the band of data within which the test results represented a switch in the specimen's resistance to the level of applied torque from passing to failing. It was estimated as the "50 percent point," that is, the torque level at which 50 percent of the specimens tested passed the test. Experimentally, the pass/fail point was approached in one of two ways. First, it was taken as the torque setting of the screwdriver at which replicate determinations on the test specimen produced a number of both passes and failures. Second, in cases where no such torque setting was found, the pass/fail point was indicated by the torque setting at which essentially all tested sections passed, while at an incrementally higher setting, essentially all the tested sections failed. In general, for each test specimen, the surface compression/shear test was conducted repeatedly at varying torque settings of the screwdriver until at least three failures and three passes were recorded at the same or at incrementally consecutive settings. (Three failures and three passes were considered the minimum necessary to have a measure of reproducibility of the results.)

4. RESULTS AND DISCUSSION

4.1 Surface Compression/Shear Test

The surface compression/shear tests were conducted on all 19 specimens (Figure 2). As a practical consideration, the testing indicated that the surface compression/shear test device was readily operated in the field for the given test specimens where the fireproofing was applied on surfaces that were relatively flat.

Only a few data points (Figure 2) were obtained for the cementitious specimens (Nos. 6 & 9), which were located on ceilings as part of a surface finish. These specimens did not fail at torque levels up to 15 lbf·in. (1.7 N·m). During testing, it was decided not to increase the torque setting of the surface compression/shear device above 15 lbf·in. (1.7 N·m) to avoid the possibility of damaging the ceilings. The torque value of 15 lbf·in. (1.7 N·m), at which these cementitious field specimens did not fail, was 50 percent higher than the greatest level of torque (10 lbf·in. or 1.1 N·m) which produced failure of the cementitious laboratory specimens (Phase 2) [2] in the surface compression/shear test.

The results of the surface compression/shear tests of the fibrous materials are presented in Figure 2. The torque levels used for all tests covered a range from 1 to 11 lbf·in. (0.1 to 1.2 N·m), indicating the variability in the resistance of the various specimens to torque applied. Specimen No. 11 displayed the least resistance with individual tests producing failures at values of

1 lbf·in. (0.1 N·m), which was the low limit of the device. Specimen No. 16 showed the highest resistance to the applied torque with one of six tests at a level of 11 lbf·in. (1.2 N·m) producing no dislodging (passing) of the material.

In the cases of Specimen Nos. 14-17 (which were from the same building and test site), it was noted during the testing that the specimens had a relatively hard surface which may have been tamped during the installation of the fireproofing. As a group, these four specimens had the greatest resistance to dislodging in the surface compression/shear tests (Figure 2).

Six specimens (Nos. 4, 7, 8, 10, 16, & 19) were not subjected to the surface compression/shear test at torque levels at which all individual specimen sections tested produced failure (i.e., dislodgment of the material). For these specimens, as is evident from Figure 2 by the open circles at the maximum applied torque, one test at the highest level resulted in passing. In these cases, additional compression/shear tests were not performed at greater values of applied torque because of the limited area over which the specimen was accessible for testing. Although a series of total failures for these six specimens was not achieved, it was considered that sufficient data were obtained indicating a shift from passing to failing in the test that pass/fail points for the six specimens could be estimated.

Figure 3 presents plots of the percent of individual tests that passed at each pre-set torque level for the series of tests

conducted on the 17 fibrous specimens. The estimated pass/fail point (see Section 3.2.1) for each specimen is marked with a short horizontal bar on these plots. A comparison of the pass/fail points of these plots also indicates the variability of the fibrous specimens' resistance to dislodging in the surface compression/shear tests. The estimated pass/fail points for the fibrous specimens ranged from 2.3 to 8.4 lbf·in. (0.26 to 0.95 N·m).

Table 6 is a summary of the surface compression/shear tests, and includes the estimated pass/fail point for each specimen, the range of torque levels over which the specimen's response in the test shifted from passing to failing, and the number of increments in that torque range. The torque range in Table 6 was taken in one of two ways: (1) the range over which the specimen displayed performance in the test from 100% passing to 100% failing (e.g., Figure 3, Specimen Nos. 1, 2, & 3); (2) in the absence of such findings, the range over which the tests were conducted (e.g., Figure 3, Specimen No. 4).

From Table 6, the relative variability of the resistance of the individual specimens to dislodging in the surface compression/shear test was estimated. Specimens requiring a greater number of increments to determine a pass/fail point were considered to have more variability. With the exception of Specimen Nos. 1, 15, & 16, the number of increments of torque over which testing was conducted to determine the pass/fail point was four or less. This indicated that resistance of the majority

of the specimens to dislodging, at least over the surface area tested, was not extremely variable. The finding that the torque increment was generally four or less compared favorably to the results of the laboratory study (Phase 2) [1]. The fibrous laboratory specimens, specially prepared under controlled conditions for the test program, showed torque ranges of four increments or less when their pass/fail points were determined. Nevertheless, it must be kept in mind that not all the field specimens were subjected to the surface compression/shear test over a range of torque values that covered material response from 100% passing to 100% failing.

Three specimens (Nos. 1, 15, & 16) had torque increments of five or greater (Table 6), and thus were considered to have relatively wider variability in their resistance to dislodging in the surface compression/shear test than the others. For two (Nos. 1 & 16) of these three specimens, a distinct pass/fail point was not measured. Rather, it was estimated as a range because the relation between percent of tests producing a passing result and the applied level of torque was not monotonic (Figure 3, Specimen Nos. 1 & 16).

Table 7 compares the pass/fail points of comparable specimens tested in the same building and site. Five comparisons were possible. The percent difference between the smallest and largest value of the estimated pass/fail point of a given set of specimens from the same building and site is an indication of the variability of the installed material at that location. The

number of such comparisons was limited due to the accessibility of the materials included in the field testing. Nevertheless, the variability between comparable specimens was considered, in general, to be relatively large. Three of the five comparisons had percent differences between estimated pass/fail points of 30 percent or more. The greatest percent difference, 68 percent, was found for the one case where four specimens were available for one building and site. The smallest difference was 7 percent for Specimen Nos. 7 & 8.

A question that has been raised concerning the use of the test devices is whether they might be used to monitor changes in friability of an in-place material over time. Based on the relatively large difference in pass/fail points for comparable specimens at a given test site (Table 7), the limited data suggest that monitoring changes in friability over time would require careful consideration of the material variability at different locations of the test site. Further data are needed to investigate material variability and to provide the basis of a statistically valid procedure for conducting tests to monitor changes with time. As a first step towards a statistical procedure, it is suggested that the EPA sampling scheme for friable surfacing materials [9] be considered.

The need for a statistically valid procedure raises a question concerning the potentially large number of tests that might have to be conducted to estimate a pass/fail point of a specimen using the currently designed surface compression/shear device. As an

example from Figure 2, 39 measurements were made for Specimen No. 15 which was time consuming. To expedite testing, the surface compression/shear device should be modified, if possible, to determine the pass/fail point directly which would decrease the number of measurements made. One suggestion is to replace the torque screwdriver in the original device (as used in the present study) with another type of commercially available screwdriver that can continuously measure the amount of torque applied to the specimen and record the maximum torque reached. By making such a modification to the surface compression/shear device, the torque level at which pieces of specimen are dislodged would be recorded as the maximum torque applied (assuming that the torque would fall off after specimen dislodgment). The benefit of recording torque at specimen dislodgment would be that one test would provide an indication of the pass/fail point[2] (i.e., the amount of torque which the specimen could resist before being dislodged). As a suggestion for using the modified surface compression/shear device, a number of tests might be conducted on a specimen, and the results of the torque level at dislodgment could be averaged and deviations calculated to estimate a pass/fail point and variability of the specimen. It is recommended that a modified surface compression/shear device that incorporates a screwdriver which records the torque at specimen dislodgment (pass/fail point) be used in further field testing. In addition, the EPA sampling scheme for friable surfacing

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[2]In practice, the test would provide a measure of the torque applied at specimen failure, and consequently, the use of the term, "pass/fail," would not be necessary.

materials [9] should be used, as an initial step, for determining the number and locations of the surface/compression shear measurements.

A final observation regarding the results of the surface compression/shear tests of the fibrous specimens is a comparison of the estimated pass/fail points with the assigned friability levels (Table 8). Figure 4 is a plot relating these two factors. The effect of the human element in assigning friability levels, based on subjective testing using the hand, is apparent. Specifically, in the relatively narrow pass/fail range of 3.5 to 4.7 lbf·in. (0.40 to 0.53 N·m), the specimens were subjectively judged to be of one of four friability levels (i.e., high, moderate-to-high, moderate, and low-to-moderate[3]). In contrast, at the extremes of the pass/fail levels measured, the assigned friability classifications were not variable. The finding that some specimens, particularly those in the transition range from high to moderate friability, displayed about the same measured value of pass/fail point while being assigned different descriptors of friability was evidence of the subjective nature of the hand test. Moreover, the finding supported the need for a non-subjective method for replacement of the hand test in monitoring over time the friability of spray-applied fire-proofings and insulations.

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[3]The low-to-moderate classification assigned to Specimen No. 19 may have been due, in part, to its painted surface.

4.2 Bulk Compression/Shear Test

The bulk compression/shear tests were conducted on 12 of the 19 field specimens (Table 5). In the case of the seven specimens not tested (Nos. 1, 6, 9, & 14-17), the fins of the compression/shear test device could not totally penetrate the specimen bulk. This finding had been previously experienced in the laboratory tests (Phase 2) for cementitious samples, and it was decided that the bulk compression/shear test should be skipped when the fins of the device could not penetrate the specimen [2]. In the present field tests, the two cementitious specimens (Nos. 6 & 9) were too hard for the fins to penetrate. On the other hand, the five fibrous specimens (Nos. 1 & 14-17) were relatively thin (about 0.5 in. or 13 mm), so that after partial penetration, the fins of the device hit against the specimen substrate which prevented their complete penetration. The inability to conduct tests on all specimens was a limitation to the use of the bulk compression/shear device.

The results of the bulk compression/shear tests are given in Figure 5. With one exception (Specimen No. 5), the fibrous specimens failed at torque levels that were 11 lbf·in. (1.2 N·m) or less. By comparison, in the laboratory (phase 2), two of the four fibrous laboratory specimens failed below this torque level in conducting the bulk compression/shear tests. These laboratory specimens were specially prepared to be highly friable [2].

Figure 6 presents plots of the percent of individual tests that passed at each pre-set torque level for the series of bulk

compression/shear tests. Each plot in the Figure indicates the estimated pass/fail point (see Section 3.2.1) for the specimen. For the bulk compression/shear tests, the estimated pass/fail point ranged from 3.5 to 10.3 lbf•in. (0.40 to 1.2 N•m), which was a range not greatly different from that observed in the surface compression/shear tests.

In general, the results of the bulk compression/shear tests were as expected in that the specimens' resistances to dislodging decreased as the torque level increased. Only Specimen No. 10 deviated from this pattern (Figure 6), and showed a relatively wide variability in resistance to dislodging in the test. It was noted during the field testing that this specimen had areas which were considerably harder than others, as indicated by squeezing and pinching by hand.

Table 9 is a summary of the results of the bulk compression/shear tests and lists the estimated pass/fail point for each specimen, the range of torque levels over which the pass/fail point was determined, and the number of increments of torque in the range. As was considered for the surface compression/shear tests, the number of torque increments used in the testing was considered as an estimate of the variability of the specimen. Only two specimens (Nos. 3 & 10) required more than four torque increments in the pass/fail point determination. These two specimens were considered the most variable in resistance to dislodging in the bulk compression/shear tests. In both cases, a specific value for the pass/fail point could not be estimated, and instead a

range of values was given. Note that Specimen No. 10 had a torque range of nine increments. This was the specimen that was observed by examination with the hand to have a noticeably variable consistency.

It was of interest to investigate whether a relationship existed between the behavior of the fibrous specimens in the surface and bulk compression/shear tests. During the concept phase of the study, it was hypothesized that surface and bulk compression/shear devices might be needed because spray-applied fireproofings could have different surface and bulk properties [1]. Figure 7 is a plot of the estimated pass/fail points of the specimens in the bulk tests versus that of the surface tests. Examination of the plot shows no discernible relation between the results of the two tests. Thus, the results of one test cannot be used to be predictive of the findings of the other. Based on Figure 7, it was concluded that, for the specimens in the field study, no relationship existed between dislodging in the surface and bulk compression/shear tests. Thus, it is suggested that, if the resistance of the surface of a fibrous specimen and also the resistance of its bulk to dislodging are of interest, then both should be measured independently using the two devices.

As a final point, it is noted that a modified test device using a screwdriver that records the maximum torque applied may be beneficial in reducing the number of tests needed to estimate the pass/fail point by determining the torque at specimen dislodgment directly. Such a modification was previously discussed (pages 16

& 17) for the surface compression/shear device. Consistent with the previous discussion, to expedite testing, GSA should consider using a modified bulk compression/shear device that incorporates a screwdriver which records the torque level at specimen dislodgment (pass/fail point) in further field testing.

4.3 Indentation Test

The indentation tests were conducted on the 19 field specimens (Table 5) at the four bearing force levels as given in Table 4. For practical reasons, the first step in carrying out the field tests was to use the indentation test device at its greatest bearing force. Thus, a series of the tests was performed at bearing force level 4, (18 lbf or 80 N). Subsequent tests were conducted in turn at the progressively lower bearing force levels only if indentation occurred at the level first selected. If no indentation was experienced at the selected bearing force (e.g., Specimen Nos. 6 & 9), then the test was terminated.

The results of the tests are shown in Figure 8. (Two plots are used for clarity). For each specimen at each bearing force level, the indentation test was generally conducted in triplicate. The indentation depth is given in "units," because the scale of the indicator rod of the indentation device is not marked in increments of length such as inches or millimetres [5]. Use of the indentation device with the amount of indentation given in "units" was acceptable for the field investigation.

However, if the device is to be commonly used, it is recommended that the scale be changed and marked in increments of length[4].

The results of the indentation tests showed different behavior for the fibrous and cementitious specimens, which was a finding comparable to that previously obtained in the laboratory indentation tests [2]. As is evident in Figure 8, the cementitious specimens (Nos. 6 & 9) essentially gave no measurable indentation at the greatest bearing force level of 18 lbf (80 N). On the other hand, the fibrous specimens were all indented to some degree, particularly at the greater bearing force levels. The depth of penetration tended to be higher as the bearing force level of the indentation test device increased, with the exception of Specimen Nos. 14-17. In the latter cases, the indentation depths were all less than one "unit" no matter what the bearing force level. This was attributed to the relatively thin application (less than about 0.5 in. or 13 mm) of the spray-applied fireproofing at this test site. Consequently, when the foot of the indentation device was pressed against the surface of the specimen, the fibrous material could only compress slightly due to influence of the rigid substrate.

The design of the indentation device was based on the concept that "moderately friable" materials may be "easily indented by hand pressure" (Table 2). It was previously reported [2] that, in the laboratory tests, some materials considered to have

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[4]For the information of the reader, each unit of the scale is about 0.3 in. (8 mm).

"moderate friability" exhibited little indentation in the indentation test. The finding was contradictory to the concept that "moderately friable" materials may be "easily indented." This raised questions as to whether the test was useful or whether it could be eliminated from the proposed test sequence (Figure 1). It was decided to postpone a decision until field tests were conducted [2].

Examination of the field results for the indentation tests provided no new data that refuted the idea that the indentation test may not be appropriate. In fact, a comparison of the indentation test results with those of the surface compression/shear tests indicated that the two methods provided comparable information:

- First, the cementitious specimens were not indented in the indentation tests and they were not dislodged in the surface compression/shear tests. Thus, the friability of the cementitious specimens could not be quantified on the basis of either of these tests.
- Second, for a given bearing force level, the fibrous specimens were generally indented to varying degrees; whereas in the compression/shear tests, these specimens underwent dislodgment at varying levels of pre-set torque. Thus, in either case, some indication of friability might be made on the basis of the results from either test.

However, the field test program uncovered a major distinction between the two test methods. The surface compression/shear test was found to be easily conducted on all the specimens and, as a

surface test, was not apparently influenced by the specimen thickness. In contrast, as just described, the indentation test was seen to be influenced by specimen thickness, which is a major limitation in using the device. Consequently, because the two test methods contributed comparable information on many of the test specimens, and because the indentation test was found to be limited by specimen thickness, it is concluded that the indentation test should not be included in a test methodology to determine the friability of spray-applied fireproofings. The resultant methodology would simplify the field testing by eliminating the indentation test which, in cases where it was appropriate for use, appeared only to be redundant because it provided data comparable to those obtained using the surface compression/shear test device.

4.4 Abrasion Test

The abrasion test was found to be readily performed in the field. In the case of the fibrous specimens, two replicate abrasion tests were conducted at one level of bearing force, 4.5 lbf (20 N) (Table 4). This was the lowest level used in the laboratory tests where it was found that, if abrasion occurred to the specimen at the low level, it also was found at the higher levels [2]. Thus, for practical purposes, the field tests were conducted at the higher levels only if the lowest level resulted in no abrasion. In the case of the cementitious specimens, the test was conducted at the bearing force level 4, 18 lbf (80 N), because of the hardness of the materials.

The abrasion test is a pass/fail procedure in that any amount of sample residue, visible on the black felt covering the foot of the test device, is the basis for "failure" of the sample. The results of the series of abrasion tests on the field specimens indicated that, with the exception of the cementitious Specimen No. 9, all failed. All specimens, except Specimen No. 9, left some residue on the felt. As was observed in the laboratory phase of the study [2], the light-colored residue from the specimens could be clearly seen on the black felt.

One cementitious specimen (No. 6) was among those producing a residue which was, in this case, granular in appearance. As previously indicated, the specimen was on a ceiling which had apparently been painted. During the tests, a question arose regarding the residue: specifically, was it an asbestos-containing material or only paint particles removed during the abrasion test. It was beyond the scope of the field study to conduct the necessary analysis of the residue to determine if it contained an asbestos material. However, such a determination would be required when using the abrasion device in practice. An advantage to the abrasion test device is that, because the felt piece on the foot of the device is removable, where warranted, it could be sent to a laboratory for analysis of residue.

During the field testing, each of the specimens was also rubbed by hand for examination of the presence of a residue (Table 2). Whenever the specimen gave a residue on the hand, it also left one on the black felt of the test device. And, when no residue

was found on the hand (Specimen No. 9), none was present on the black felt. Another advantage of the abrasion test device is that the bearing force level is pre-set, which eliminates the subjectivity of using the hand. Hand strengths can vary significantly from person to person [2].

4.5 Impact Test

Although the impact test could be readily conducted in the field, it was conducted on only eight specimens (Table 5). The tests of the fibrous specimens using the surface compression/shear device indicated that these spray-applied materials were dislodged, in many cases, at relatively low torque levels. Thus, to avoid the possible disruption of the materials, impact tests were not performed. Moreover, in conducting the field study, the interest in the impact test was primarily centered on the cementitious materials. They are generally considered to be less friable than the fibrous materials, and some may be judged to be non-friable [2,5]. The impact test was designed to aid decisions regarding classifying spray-applied materials in these friability categories [1].

The impact test is a pass/fail procedure in that any amount of indentation produced on the sample is a "failure." This concept was proposed in the design of the prototype impact device to be consistent with the descriptors of friability indicating that "not friable" materials "cannot be damaged by hand," whereas "low friable" materials "can be indented by forceful impact." In the case of the two cementitious specimens subjected to the impact

test, one was seen to have passed, while the other was judged to have failed. Specimen No. 9 passed in that no indentation was discernible. Specimen No. 6 was described as failing in that a very slight, yet noticeable, indentation occurred.

5. SUMMARY AND RECOMMENDATIONS

This report describes results of the third and final phase of a study to develop a field test method for measuring the friability of spray-applied fireproofing and thermal insulation materials. Field tests to assess the friability of in-place fireproofings were performed on 19 specimens located in seven buildings in the Baltimore-Washington DC area. All specimens had been applied on relatively flat surfaces. Seventeen of the specimens were fibrous and two were cementitious. The tests were conducted using prototype devices developed earlier in the study (Phase 1) for conducting surface and bulk compression/shear, indentation, abrasion, and impact tests. As expected, the field specimens displayed varying response to dislodgment or indentation in the tests.

A summary of the key findings for tests conducted using each of the prototype devices is as follows:

- Surface Compression/Shear Test. This test was readily applied to the relatively flat specimens. Differences in resistance to dislodgment were observed for the two types of specimens: the fibrous materials were dislodged at torque levels of 11 lbf·in. (1.2 N·m) or less, while the cementitious materials were not dislodged at torques up to 15 lbf·in. (1.7 N·m). Where comparable replicate specimens were available at a test site, variability in the test results was, in some cases, found to be 30 percent or greater. This finding indicated that use of the surface compression/shear test for monitoring changes in the resistance of spray-applied fireproofings to dislodgment over time may require extensive initial characterization using statistical techniques. Statistical differences among comparable data in the present study were not determined because of the limited number of specimens available for comparison.

  The Surface Compression/Shear Test results for the fibrous specimens were compared to levels of friability assigned based on hand testing and using the friability descriptors

given in algorithm procedures. Some fibrous specimens, which displayed about the same value of the pass/fail point, as determined by the Surface Compression/Shear Test, were assigned, by an experienced inspector, different descriptors of friability within a range of low-to-moderate to high. This finding supported the hypothesis that the hand is not a reliable instrument for assigning friability levels and that a more objective test, such as the Surface Compression/Shear Test, is needed.

- Bulk Compression/Shear Test. The Bulk Compression/Shear Test was not applicable to testing all the specimens in the study. The reason was that the fins of the test device could not penetrate completely into the bulk of some of the specimens. Some fibrous materials were applied in relatively thin layers, and the fins of the device struck against the substrate of the fireproofing, which prevented complete penetration. On the other hand, the cementitious specimens were too hard to penetrate. For those fibrous specimens tested, varying resistance to dislodgment in the test was found. A comparison of the results of the Surface Compression/Shear Tests of the fibrous specimens with those of the Bulk Compression/Shear Tests showed no relation between the two, indicating that the results from one are not predictive of the results from the other. Thus, for relatively thick spray-applied specimens for which the device was found to be applicable, both Surface and Bulk Tests need to be conducted to determine surface and bulk resistances to dislodging. One test will not suffice.

- Indentation Test. In the Indentation Test, the results varied according to the type of material. The two cementitious specimens were not penetrated during indentation testing; whereas all fibrous specimens showed some penetration. With the exception of one set of specimens, the fibrous materials showed a tendency to give increased depth of penetration with an increase in bearing force level. The exception was that relatively thin fibrous specimens underwent little penetration, and the penetration was independent of the bearing force level of the indentation device. This major limitation of the test was due to the rigid substrate on which the thin fireproofing was installed. It was also found that the Indentation Tests provided no information additional to that given by the Surface Compression/Shear Tests. For these reasons, it was recommended that the Indentation Test be eliminated from the test sequence proposed in Phase 2 of the study.

- Abrasion Test. All specimens were readily tested using the Abrasion Test device. With one exception (a cementitious product), a residue was produced indicating abrasion of the specimens under the test conditions. These results were comparable to rubbing the specimens by hand in that those specimens that produced a residue in the test also gave a residue when rubbed by hand. An advantage of the prototype

Abrasion Test device is that it limits the use of the hand which can have variable force, and allows application of a reproducible bearing force to the specimens during abrasion testing.

- Impact Test. The Impact Test was readily conducted in the field on both fibrous and cementitious specimens. Nevertheless, it was primarily of interest in the case of the cementitious specimens. The test was designed to provide data as to whether a material might be classified as friable or non-friable. Cementitious specimens are generally harder than fibrous materials and, depending on the hardness, may be classified as of low friability or non-friable. In the field testing, data on the performance of the Impact Test device were limited. One cementitious specimen was slightly indented on impact using the device, whereas another cementitious specimen gave no indentation. A few fibrous specimens were subjected to the Impact Test, and all of them were readily indented.

In conclusion, the field tests confirmed that the goal of the study had been achieved. Therefore, it is recommended that the Surface and Bulk Compression/Shear, Abrasion, and Impact tests be used by GSA in assessing friability.

The four test devices were found to be readily operated in the field. The methods developed in the study will provide GSA field inspectors the means to assess friability without using their hands as the "test devices," which is the present practice. Hand forces can vary significantly from person to person.

The assessments of friability should be performed using the flow diagram given in Figure 9. This diagram is similar to that in Figure 1, except that the use of the indentation test has been omitted, based on the results of the field tests. As was considered for the diagram in Figure 1, that given in Figure 9 outlines a systematic procedure for conducting tests in sequence.

Consistent with the observations in the field tests, fibrous materials, which are generally considered to be more friable than cementitious products, would be expected to be dislodged (i.e., produce a "yes" in the diagram) in the Compression/Shear Tests. Conversely, as was observed in the field tests, the cementitious materials would be less likely to be dislodged in the compression/shear tests, and might need to be subjected to an Abrasion Test, or even an Impact Test.

If the testing is to be used to monitor changes in the friability of the specimens, an appropriate, statistically valid procedure should be applied to account for the variability of the material. Development of such a procedure was beyond the scope of this study. For field testing, it may be advantageous to modify the surface and bulk compression/shear devices to incorporate a screwdriver that records the torque level applied when the specimen is dislodged. The potential benefit gained by the modification is a reduction in the number of tests that need to be conducted in estimating the pass/fail points of the specimen.

As a final note, although the objective of the present study was to develop a field test procedure for assessing the friability of sprayed-applied asbestos-containing materials, the test devices may have broader use. In particular, the devices may provide a practical quantitative determination of the friability of spray-applied (non asbestos-containing) fireproofings and thermal insulations currently used by GSA.

6. ACKNOWLEDGMENTS

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Table 1. Summary of the Specimens Included in the Field Tests

Specimen No.	Building No.	Site No.	Material Type	Assigned Friability[a] Level
1	1	1	Fibrous	Moderate
2	1	1	Fibrous	Moderate
3	1	1	Fibrous	Moderate
4	1	2	Fibrous	--------[b]
5	2	1	Fibrous	Moderate to High
6	3	1	Cementitious	Low
7	3	2	Fibrous	High
8	3	2	Fibrous	High
9	4	1	Cementitious	Not Friable
10	5	1	Fibrous	High
11	5	1	Fibrous	High
12	5	2	Fibrous	High
13	5	2	Fibrous	High
14	6	1	Fibrous	Moderate
15	6	1	Fibrous	Moderate
16	6	1	Fibrous	Moderate
17	6	1	Fibrous	Moderate
18	7	1	Fibrous	High
19[c]	7	1	Fibrous	Low to Moderate

a. The friability levels were assigned to the specimens based on the judgment of a GSA industrial hygienist, experienced in asbestos abatement, using the descriptions given in Tables 2 & 3. Since the judgment was subjective, it was possible that other investigators might have assigned other friability levels.
b. The friability level of this sample was not judged, because the GSA industrial hygienist was not present during testing.
c. The surface of this specimen had been painted.

Table 2. Descriptors of Levels of Friability from the EPA Algorithm, As Published in 1982[a]

Friability Level	Descriptor
Not Friable	Material that is hard and crusty. Cannot be damaged by hand. Sharp tools required to penetrate the material.
Low Friability	Material that is difficult yet possible to damage by hand. Material can be indented by forceful impact. If the granular, cementitious asbestos-containing material is rubbed, it leaves granules on the hand but no powder.
Moderate Friability	Fairly easy to dislodge and crush or pulverize. Material can be removed in small or large pieces. Material is soft and can be easily indented by hand pressure. The granular, cementitious asbestos-containing material leaves a powder residue on the hands when rubbed.
High Friability	The material is fluffy, spongy, or flaking and may have pieces hanging down. Easily crushed or pulverized by minimal hand pressure. Material may disintegrate or fall apart when touched.

a. This table is taken from Reference 5. It is noted that EPA no longer uses an algorithm for assessing the condition of asbestos-containing materials [3].

Table 3. Descriptors of Levels of Friability from the GSA Algorithm[a]

Friability Level	Descriptor
Low Friability	Material that could be damaged by hand only if heavy force is applied. This includes most troweled materials.
Moderate Friability	Fairly easy to dislodge and crush or pulverize by hand. Material may be removed in small or large pieces.
High Friability	The material is fluffy, spongy, or flaking and may have pieces hanging down.

a. This table is taken from Reference 4.

Table 4. Values of Test Device Parameters Used in the Field Tests

Test	Parameter			
Surface Compression/ Shear	Torque Level:	1 to 10 lbf·in. in 1 lbf·in. increments (0.1 to 1.1 N·m in 0.11 N·m increments)		
	Bearing Force Level:	2 lbf (10 N)		
Bulk Compression/ Shear	Torque Level:	2 to 30 lbf·in. in 1 lbf·in. increments (0.2 to 3.3 N·m in 0.11 N·m increments)		
Indentation	Bearing Force Level:	<u>Descriptor</u>	<u>Value</u>	
		Level 1	4.5 lbf (20 N)	
		Level 2	9 lbf (40 N)	
		Level 3	13.5 lbf (60 N)	
		Level 4	18 lbf (80 N)	
Abrasion	Bearing Force Level:	<u>Descriptor</u>	<u>Value</u>	
		Level 1	4.5 lbf (20 N)	
		Level 2	9 lbf (40 N)	
		Level 3	13.5 lbf (60 N)	
		Level 4	18 lbf (80 N)	
Impact	Type of Tip:	<u>Descriptor</u>	<u>Diameter</u>	<u>Shore Hardness</u>
		No. 1	1.5 in. (38 mm)	Type 2A, 65

Table 5. Summary of Tests Conducted on the Field Specimens

Specimen No.	Test: Surface Comp/Shear	Bulk Comp/Shear	Indent.	Abrasion	Impact
1	+		+	+	
2	+	+	+	+	
3	+	+	+	+	
4	+	+	+		
5	+	+	+	+	
6	+		+	+	+
7	+	+	+	+	+
8	+	+	+	+	+
9	+		+	+	+
10	+	+	+	+	
11	+	+	+	+	
12	+	+	+	+	
13	+	+	+	+	
14	+		+	+	+
15	+		+	+	+
16	+		+	+	+
17	+		+	+	+
18	+	+	+	+	
19	+	+	+	+	

Table 6. Summary of Surface Compression/Shear Test Results for the Fibrous Specimens

Specimen No.	Estimated Pass/Fail Point[a] lbf·in	(N·m)	Range of Torque Levels[b] lbf·in	(N·m)	Increments in the Torque Range No.
1	4-6	0.5-0.6	3-7	0.3-0.8	5
2	4.5	0.51	3-6	0.3-0.7	4
3	4.5	0.51	4-5	0.5-0.6	2
4	3.8	0.43	3-6	0.3-0.7	4
5	3.7	0.42	3-5	0.3-0.6	3
7	4.3	0.49	3-5	0.3-0.6	3
8	4.6	0.52	4-5	0.5-0.6	2
10	3.0	0.34	2-5	0.2-0.6	4
11	2.3	0.26	1-3	0.1-0.3	3
12	3.8	0.43	3-4	0.3-0.5	2
13	3.4	0.38	2-4	0.2-0.5	3
14	8.4	0.95	6-9	0.7-1	4
15	7.5	0.85	6-11	0.7-1.2	6
16	5-7	0.6-0.7	4-11	0.5-1.2	8
17	6.8	0.77	6-8	0.7-0.9	3
18	4.2	0.47	3-5	0.3-0.6	3
19	6.4	0.72	6-7	0.7-0.8	2

a. See text for explanation, Section 3.2.1.
b. The torque range of testing was defined in one of two ways: (1) the range of which the specimen displayed performance in the test from 100 % passing to 100 % failing; (2) in the absence of such findings, the range over which the tests were conducted.

Table 7. Variability Between Specimens From the Same Building and Site, As Determined Using Surface Compression/Shear Data.

Specimen No.	Building No.	Site No.	Estimated Pass/Fail Point[a] lbf·in	(N·m)	Difference[b] %
1	1	1	4-6	0.5-0.6	50
2	1	1	4.5	0.51	
3	1	1	4.5	0.51	
7	3	2	4.3	0.49	7
8	3	2	4.6	0.52	
10	5	1	3.0	0.34	30
11	5	1	2.3	0.26	
12	5	2	3.8	0.43	12
13	5	2	3.4	0.38	
14	6	1	8.4	0.95	68
15	6	1	7.5	0.85	
16	6	1	5-7	0.6-0.7	
17	6	1	6.8	0.77	

a. See text for explanation, Section 3.2.1.
b. This is the percent difference between the smallest and largest value of the estimated pass/fail point of a given set of specimens from the same building and site.

Table 8. Comparison of the Estimated Pass/Fail Points (Surface Compression/Shear Test) With the Assigned Friability Levels

Specimen No.[b]	Building No.	Site No.	Estimated Pass/Fail Pt. lbf·in	(N·m)	Assigned Friability[a] Level
1	1	1	4-6	0.5-0.6	Moderate
2	1	1	4.5	0.51	Moderate
3	1	1	4.5	0.51	Moderate
4	1	2	3.8	0.43	--------[c]
5	2	1	3.7	0.42	Moderate to High
7	3	2	4.3	0.49	High
8	3	2	4.6	0.52	High
10	5	1	3.0	0.34	High
11	5	1	2.3	0.26	High
12	5	2	3.8	0.43	High
13	5	2	3.4	0.38	High
14	6	1	8.4	0.95	Moderate
15	6	1	7.5	0.85	Moderate
16	6	1	5-7	0.6-0.7	Moderate
17	6	1	6.8	0.77	Moderate
18	7	1	4.2	0.47	High
19	7	1	6.4	0.72	Low to Moderate

a. The friability levels were assigned to the specimens based on the judgment of a GSA industrial hygienist, experienced in asbestos abatement, using the descriptions given in Tables 2 & 3. Since the judgment was subjective, it was possible that other investigators might have assigned other friability levels.

b. Fibrous specimens only.

c. The friability level of this sample was not judged, because the GSA industrial hygienist was not present during testing.

Table 9. Summary of Bulk Compression/Shear Test Results for the Fibrous Specimens

Specimen No.	Estimated Pass/Fail Point[a] lbf·in	Estimated Pass/Fail Point[a] (N·m)	Range of Torque Levels[b] lbf·in	Range of Torque Levels[b] (N·m)	Increments in the Torque Range No.
2	8.4	0.95	6-9	0.7-1	4
3	7-8	0.8-0.9	6-10	0.7-1.1	5
4	3.5	0.40	3-4	0.3-0.5	2
5	12.8	1.45	13-14	1.5-1.6	2
7	5.5	0.62	5-6	0.6-0.7	2
8	5.7	0.64	5-6	0.6-0.7	2
10	2-8	0.2-0.9	1-9	0.1-1	9
11	6.0	0.68	5-8	0.6-0.9	4
12	7.5	0.85	7-8	0.8-0.9	2
13	6.7	0.76	5-8	0.6-0.9	4
18	7.4	0.84	6-8	0.6-0.9	3
19	10.3	1.16	9-11	1 -1.2	3

a. See text for explanation, Section 3.2.1.

b. The torque range of testing was defined in one of two ways: (1) the range of which the specimen displayed performance in the test from 100 % passing to 100 % failing; (2) in the absence of such findings, the range over which the tests were conducted.

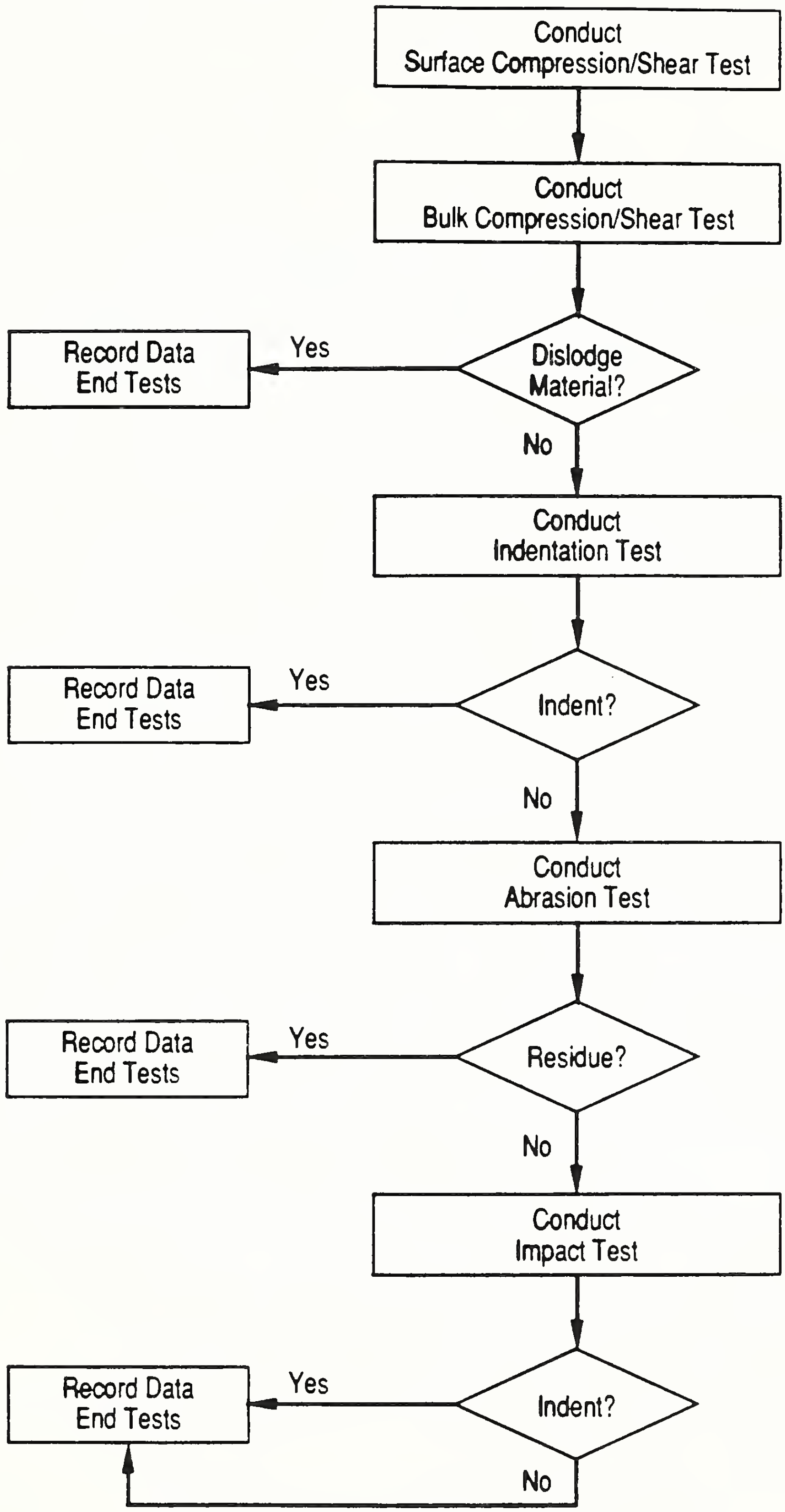

Figure 1. Flow Diagram, Proposed in Phase 2 of the Study, Indicating the Sequence of Conducting Friability Tests.

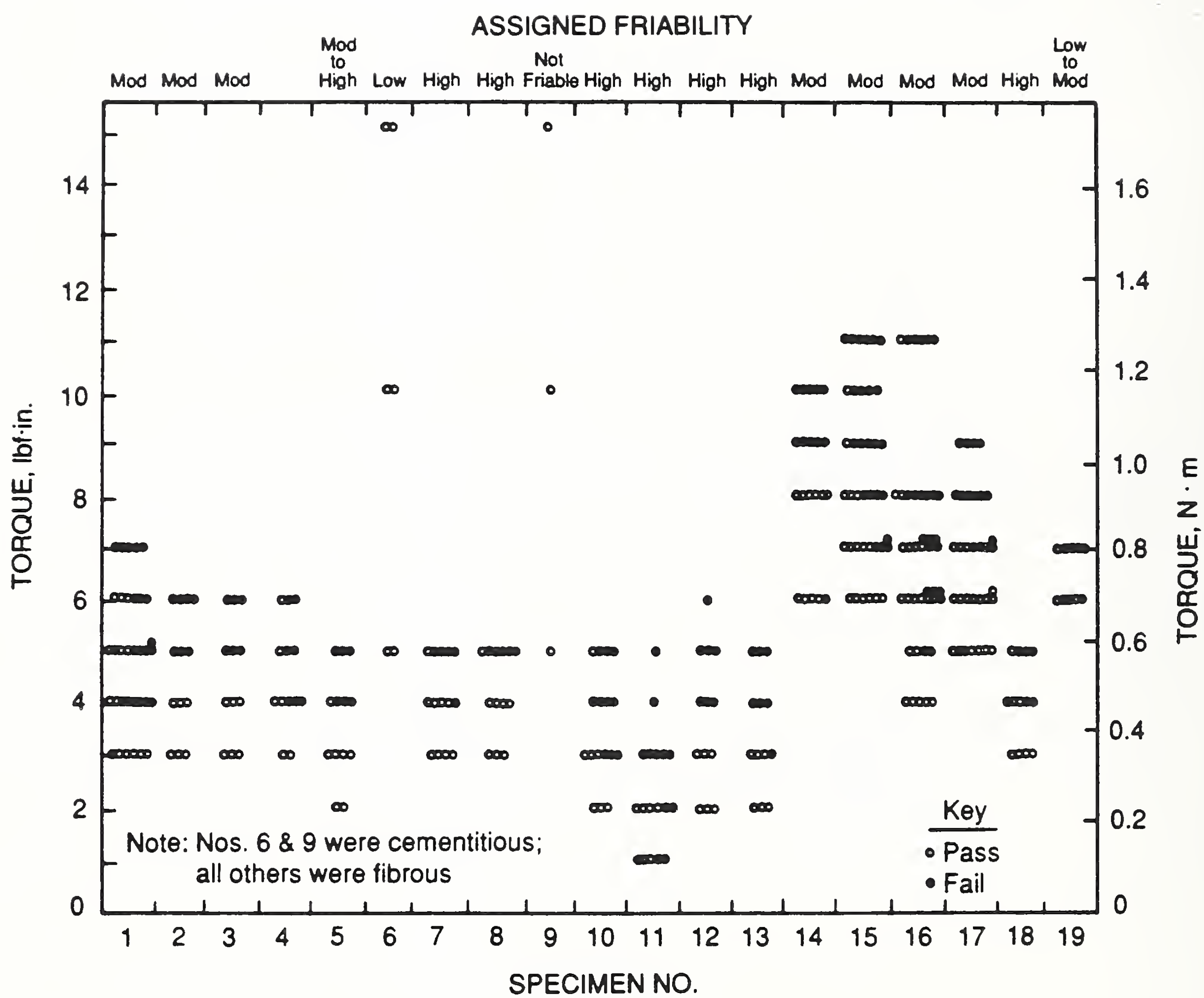

Figure 2. Results of the Surface Compression/Shear Tests. "Pass" Indicates That the Specimen was not Dislodged at the Pre-Set Torque Level, Whereas "Fail" Indicates That Dislodgment Occurred.

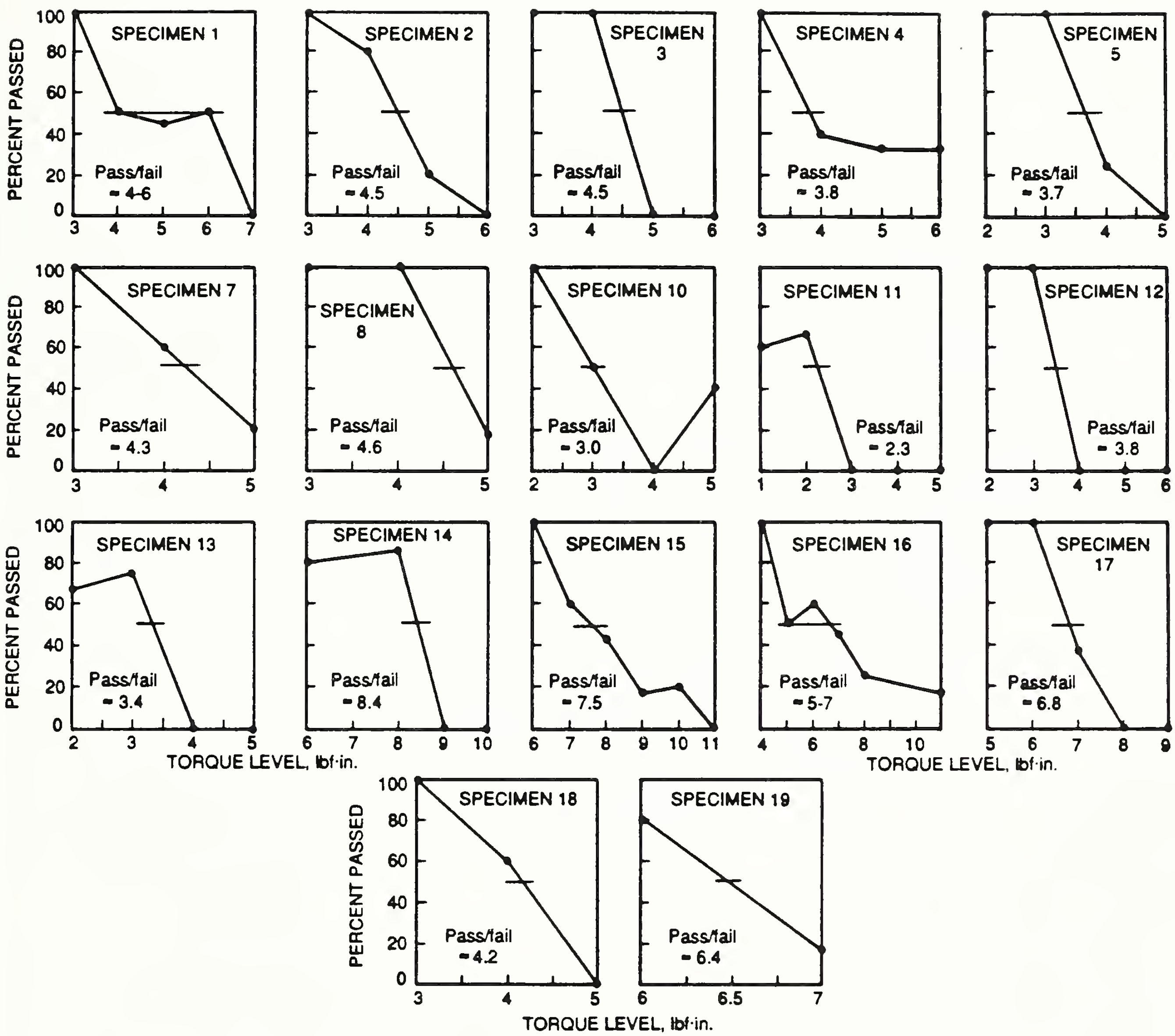

Figure 3. Results of the Surface Compression/Shear Tests: Percent of the Individual Tests Producing a Pass Versus the Torque Level. Pass/Fail Points Given on the Plots Are in Units of lbf·in.

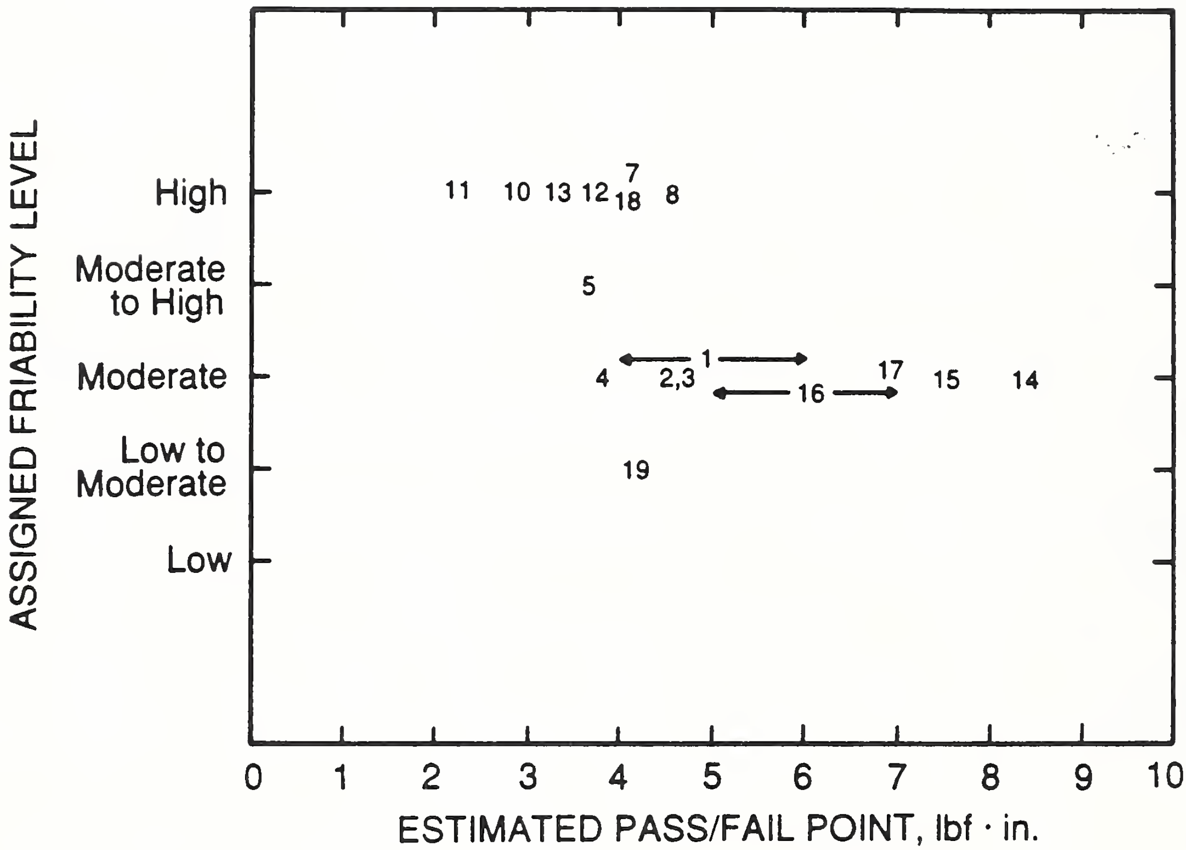

Figure 4. Plot of the Assigned Friability Level of the Fibrous Specimens Versus Their Estimated Pass/Fail Point Determined in the Surface Compression/Shear Tests.

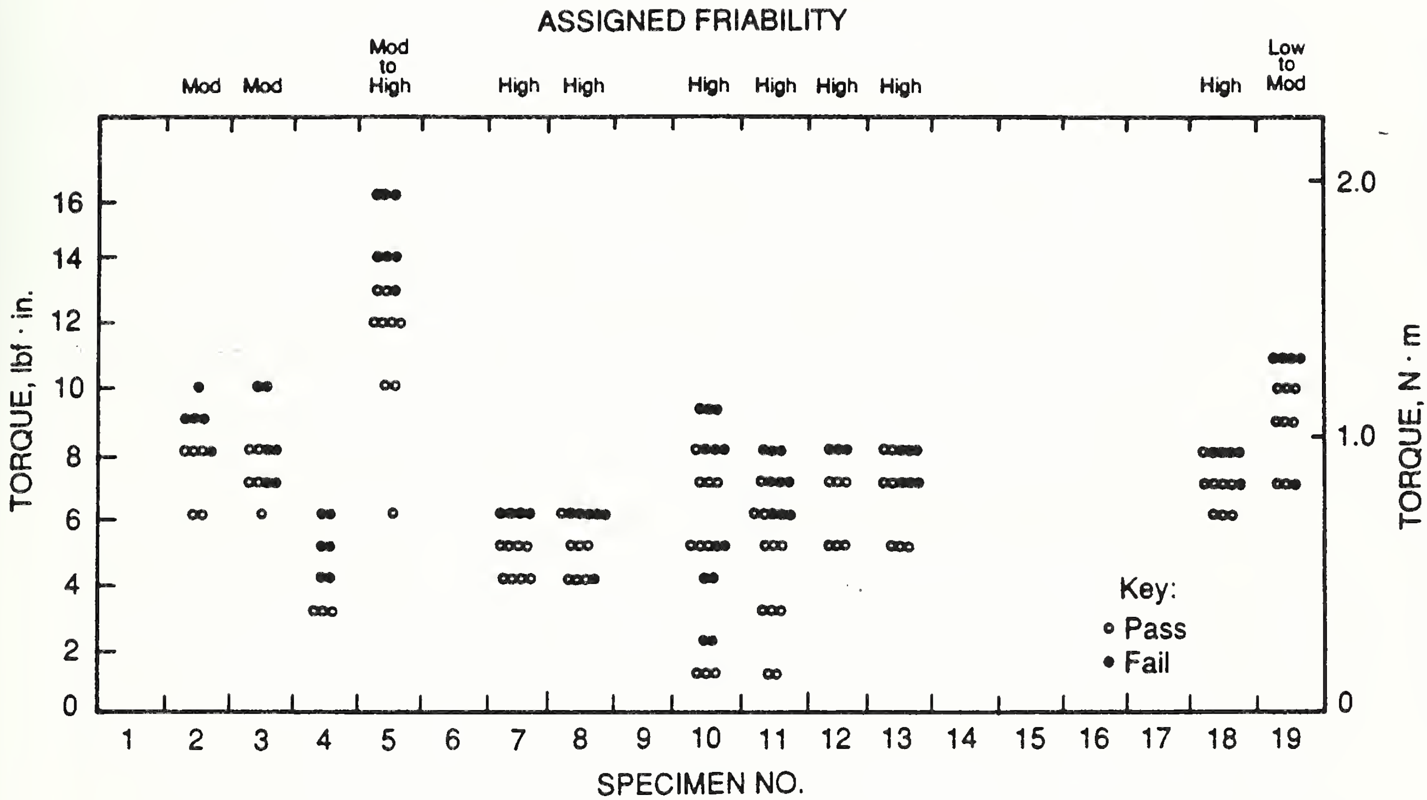

Figure 5. Results of the Bulk Compression/Shear Tests. "Pass" Indicates That the Specimen was not Dislodged at the Pre-Set Torque Level, Whereas "Fail" Indicates That Dislodgment Occurred.

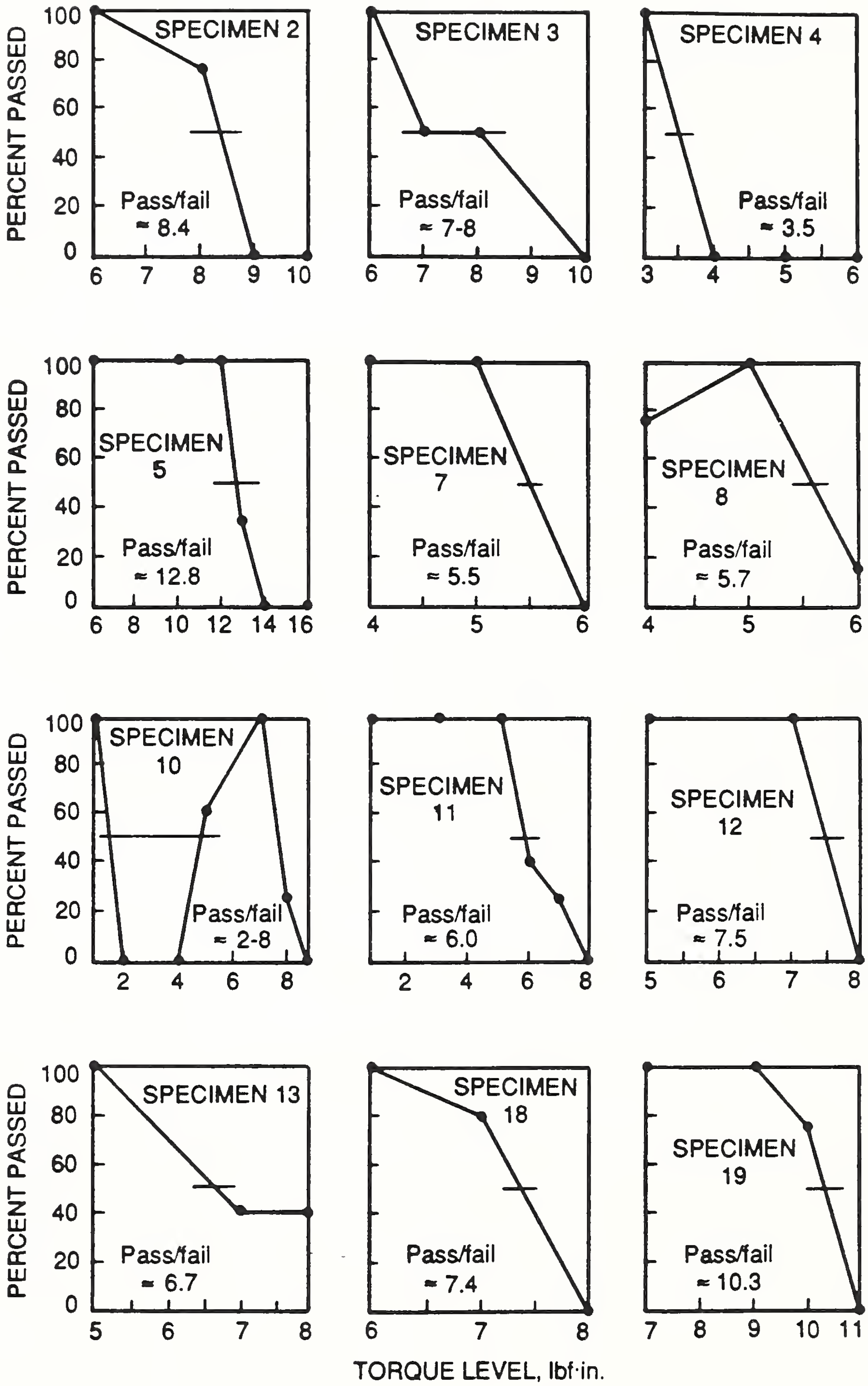

Figure 6. Results of the Bulk Compression/Shear Tests: Percent of the Individual Tests Producing a Pass Versus the Torque Level. Pass/Fail Points Given on the Plots Are in Units of lbf·in.

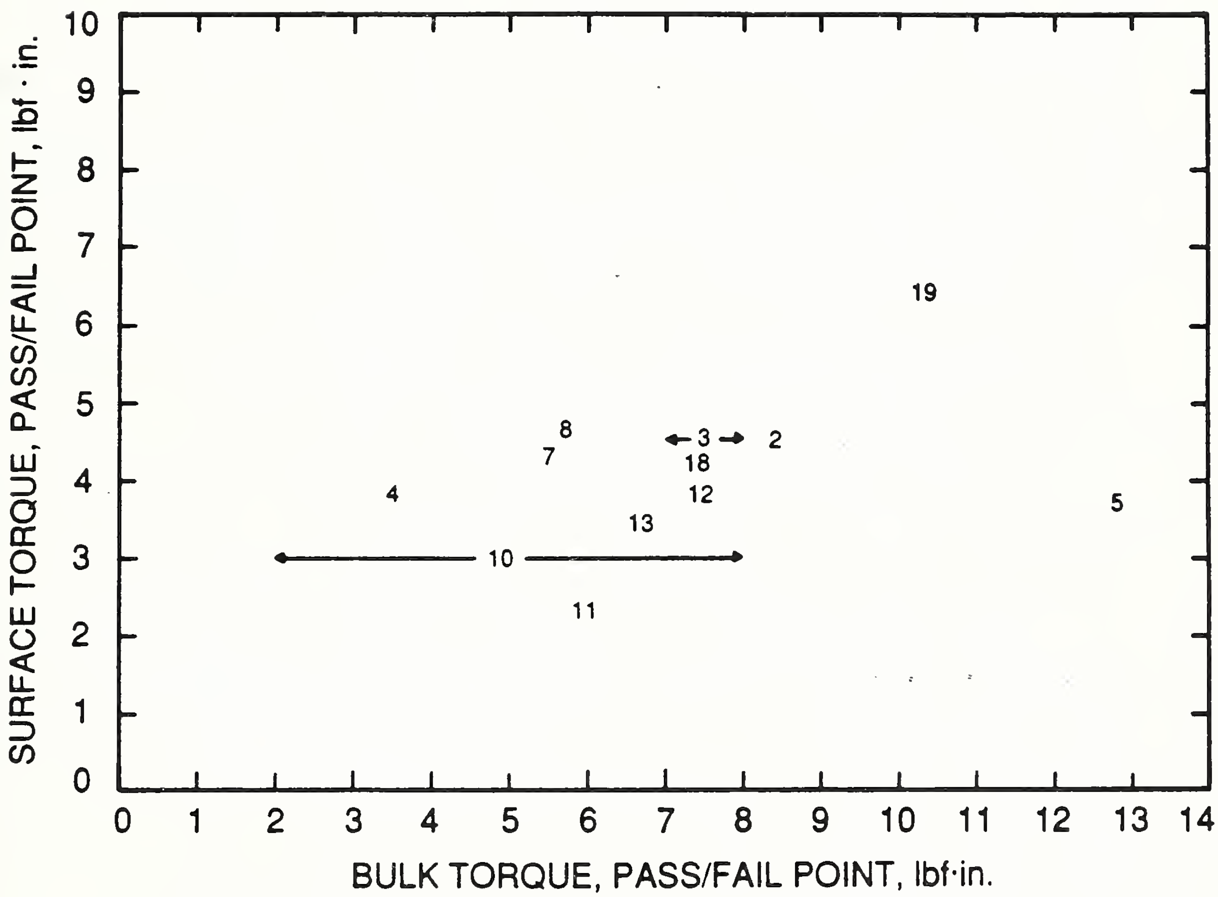

Figure 7. Comparison of the Estimated Pass/Fail Points of the Fibrous Specimens Determined in the Surface and Bulk Compression/Shear Tests.

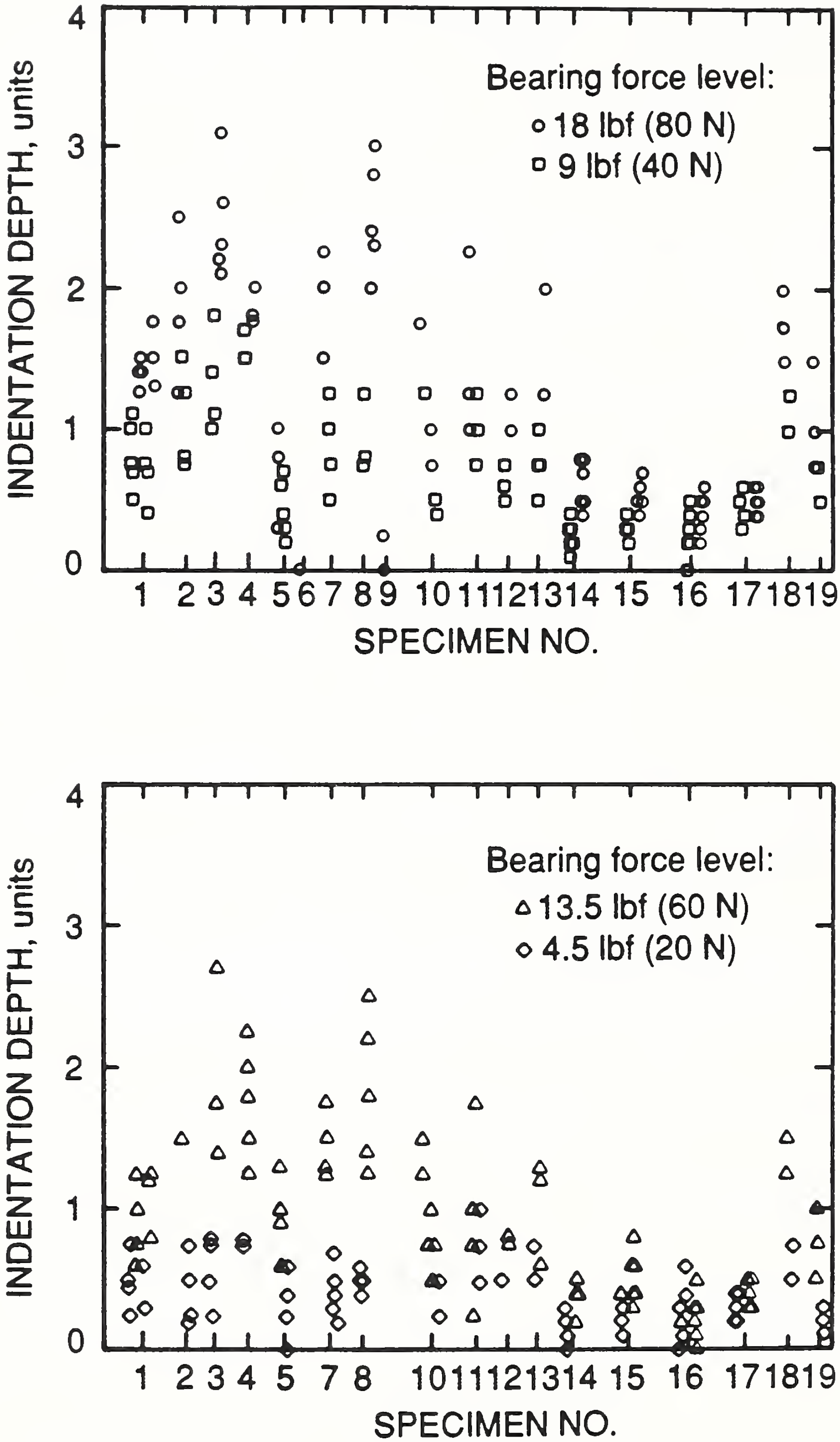

Figure 8. Results of the Indentation Tests.

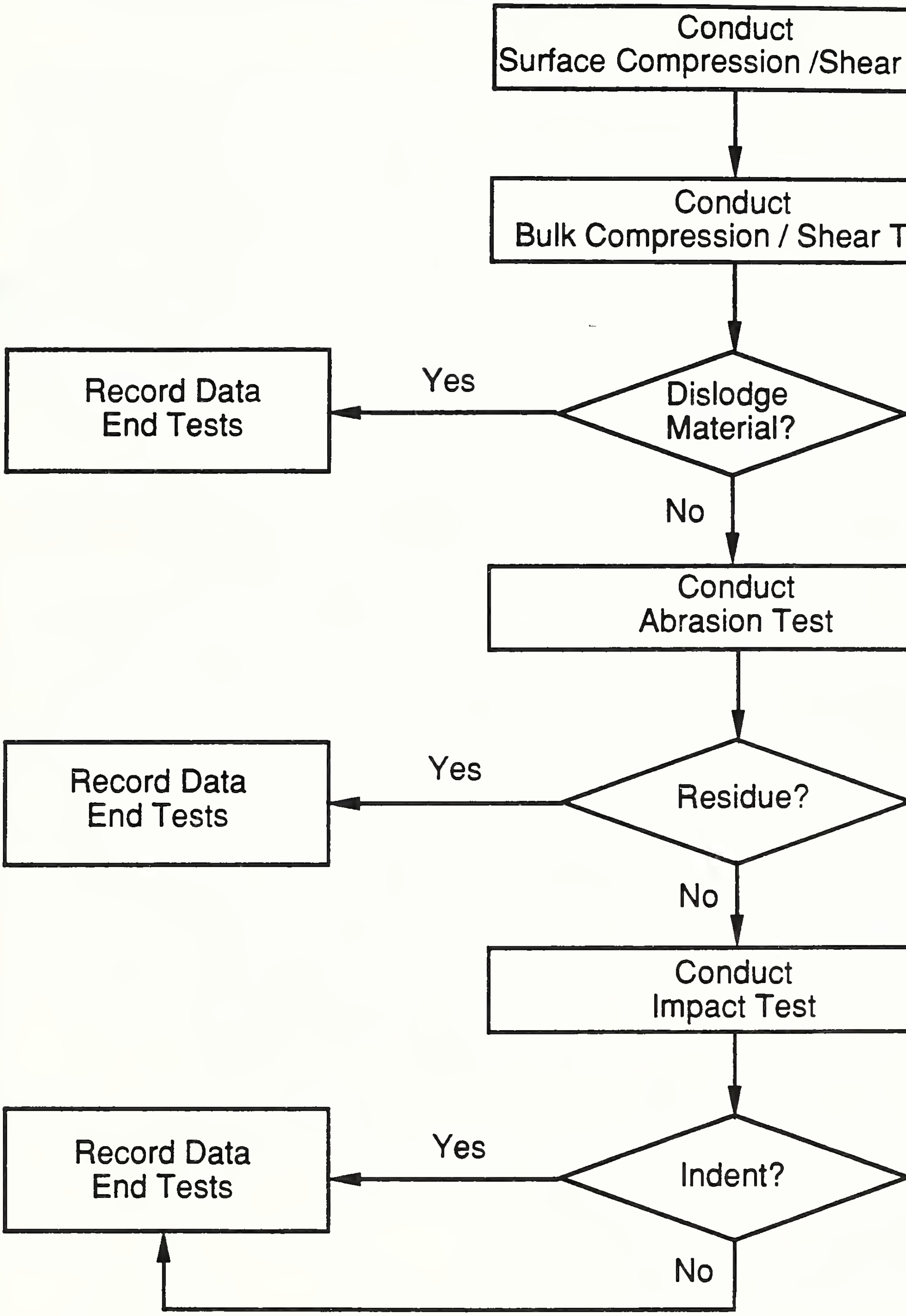

Figure 9. Final Flow Diagram Recommending the Sequence of Conducting Friability Tests Using the Prototype Devices.

APPENDIX A. PHOTOGRAPHS OF THE PROTOTYPE TEST DEVICES

This appendix presents photographs of the prototype test devices for conducting the surface and bulk compression/shear, indentation, abrasion, and impact tests on spray-applied fireproofings and thermal insulations. These photos were previously published, but are again presented for the convenience of those who may not have the earlier report [2].

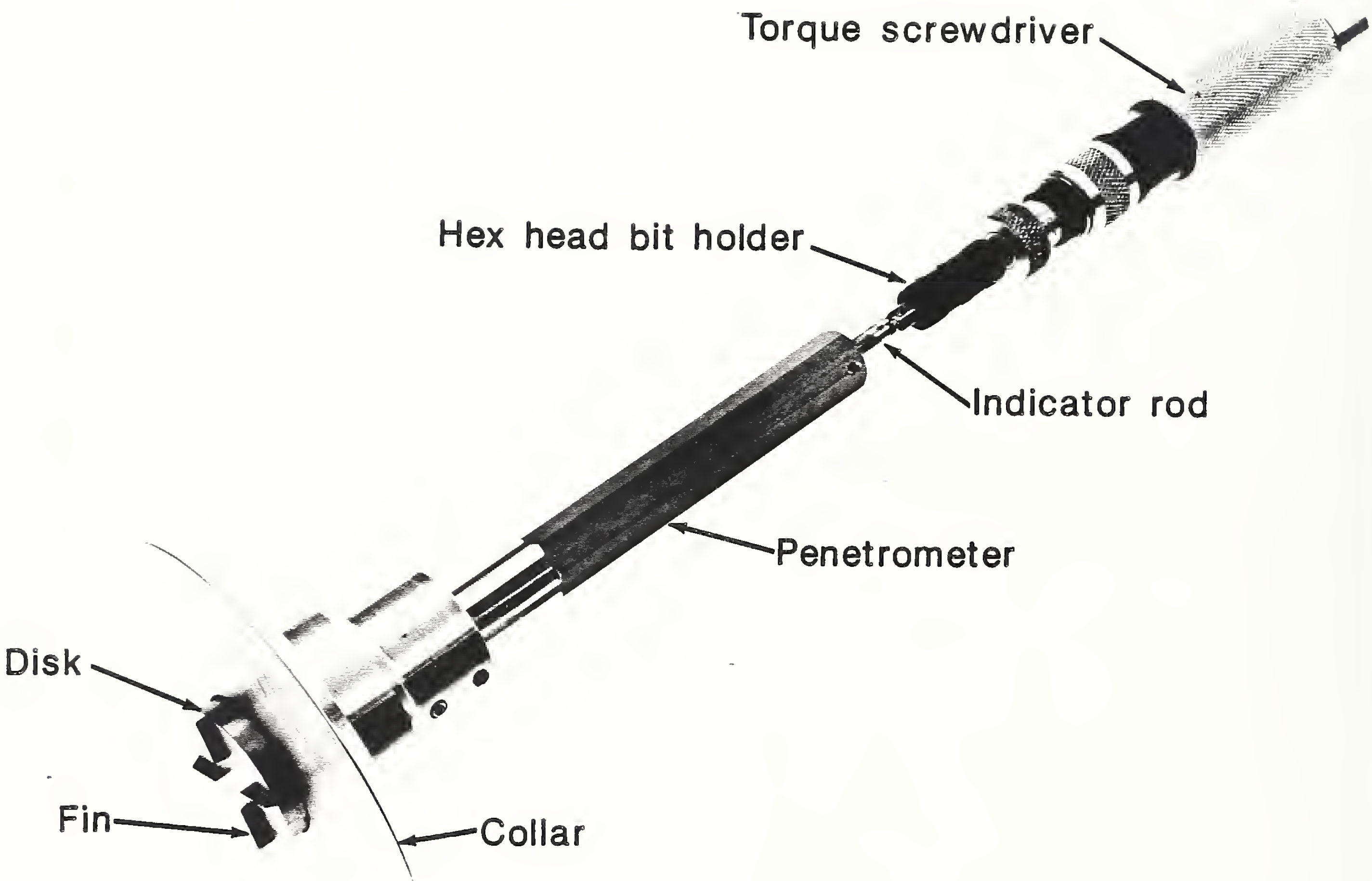

Figure A1. Prototype Device for Conducting Surface Compression/ Shear Tests

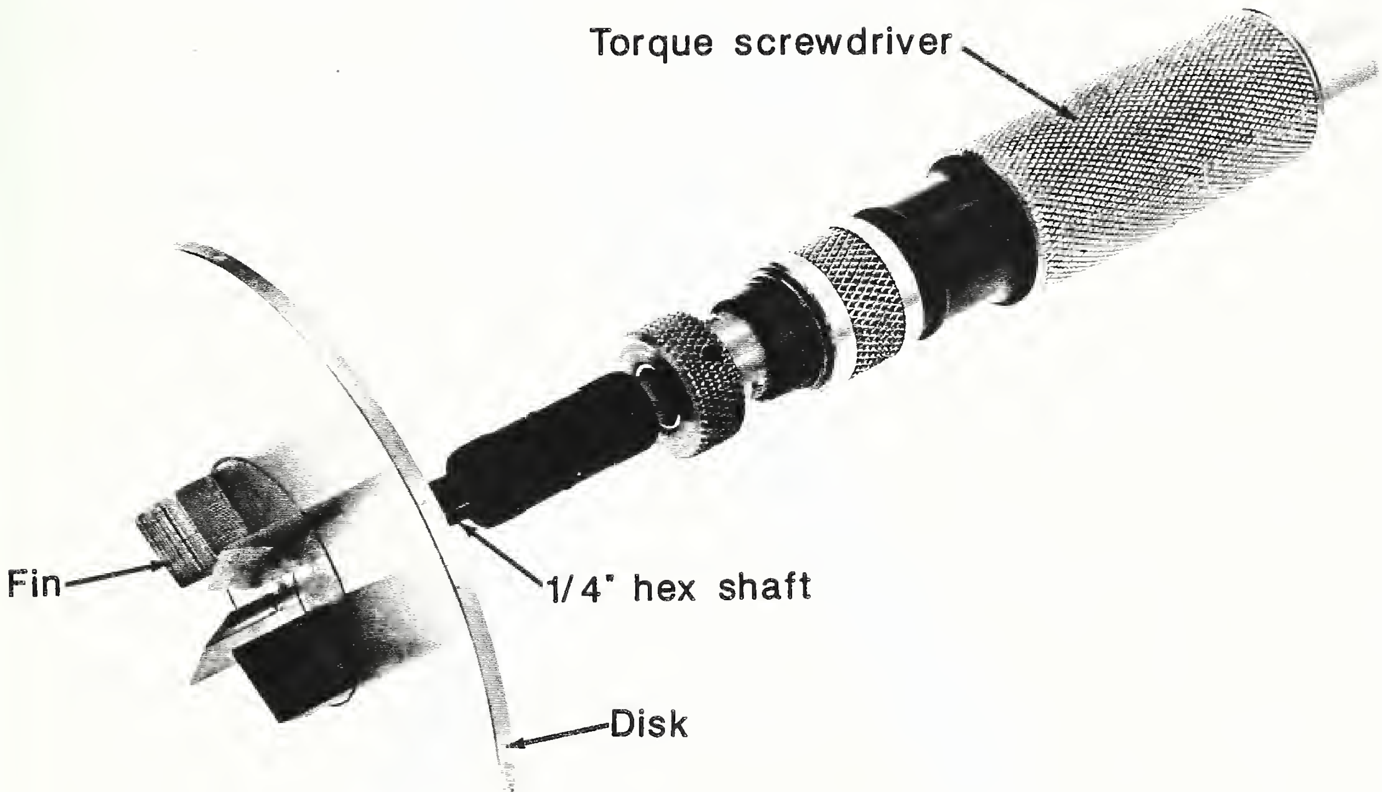

Figure A2. Prototype Device for Conducting Bulk Compression/ Shear Tests

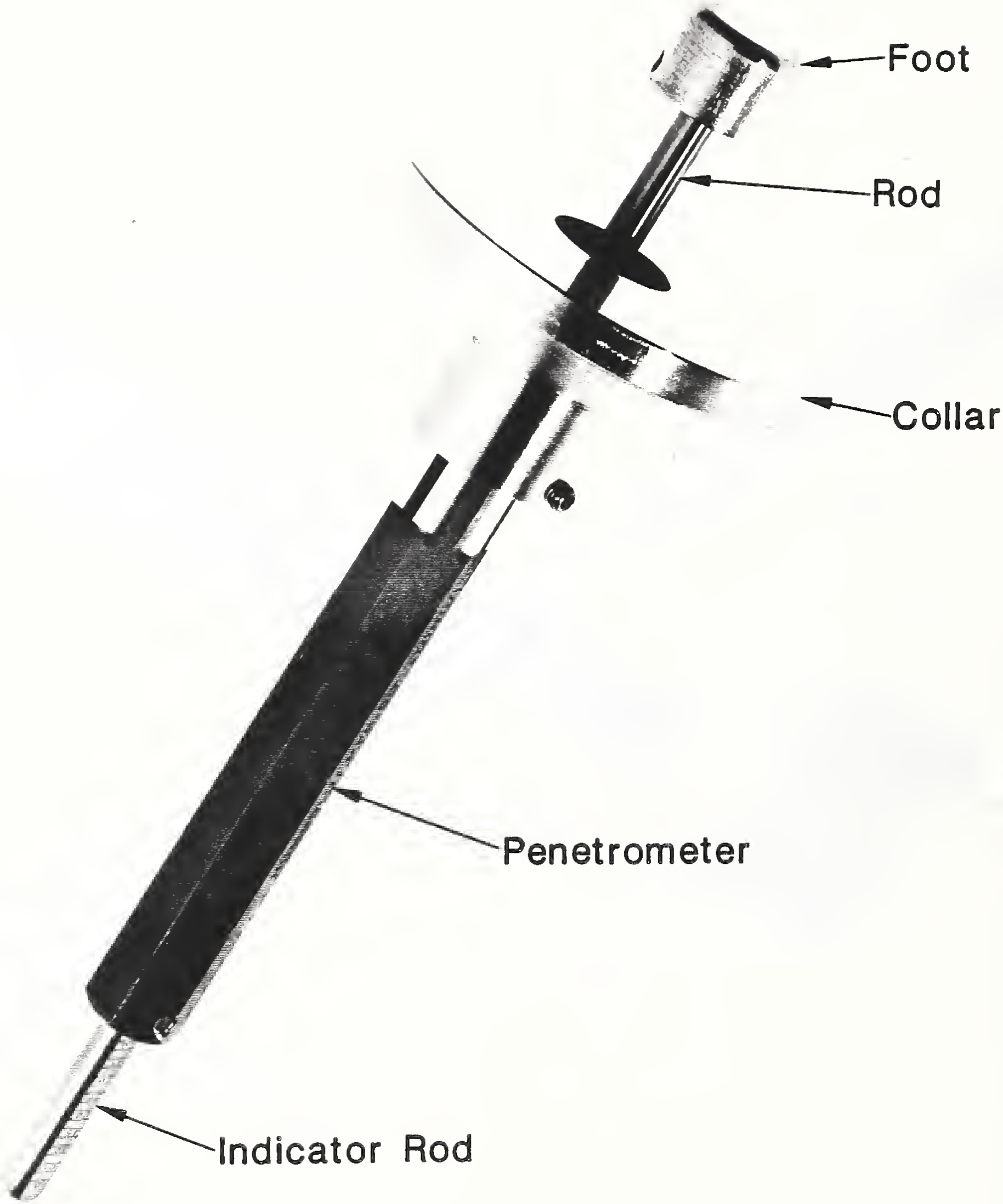

Figure A3. Prototype Device for Conducting Indentation Tests

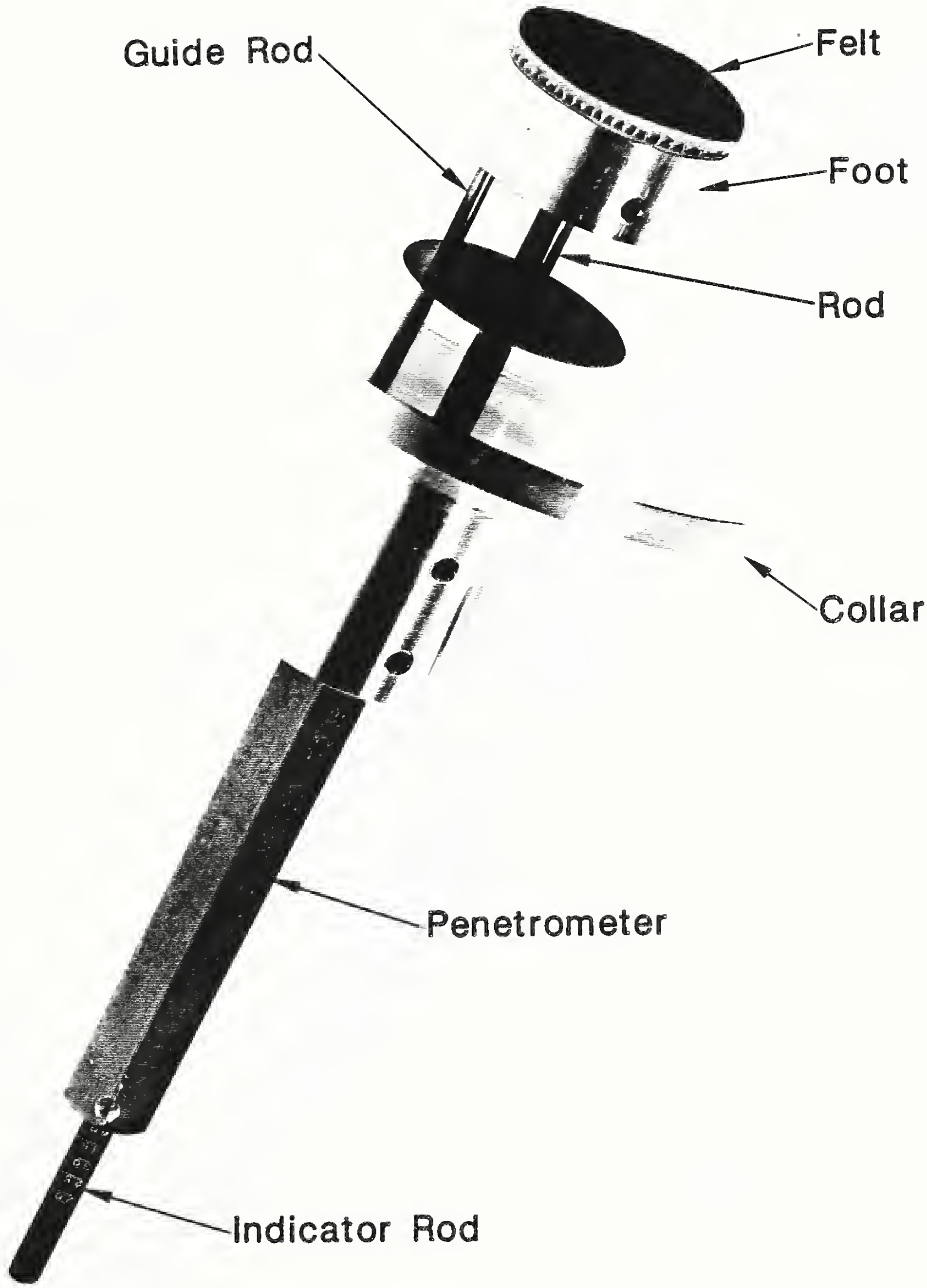

Figure A4. Prototype Device for Conducting Abrasion Tests

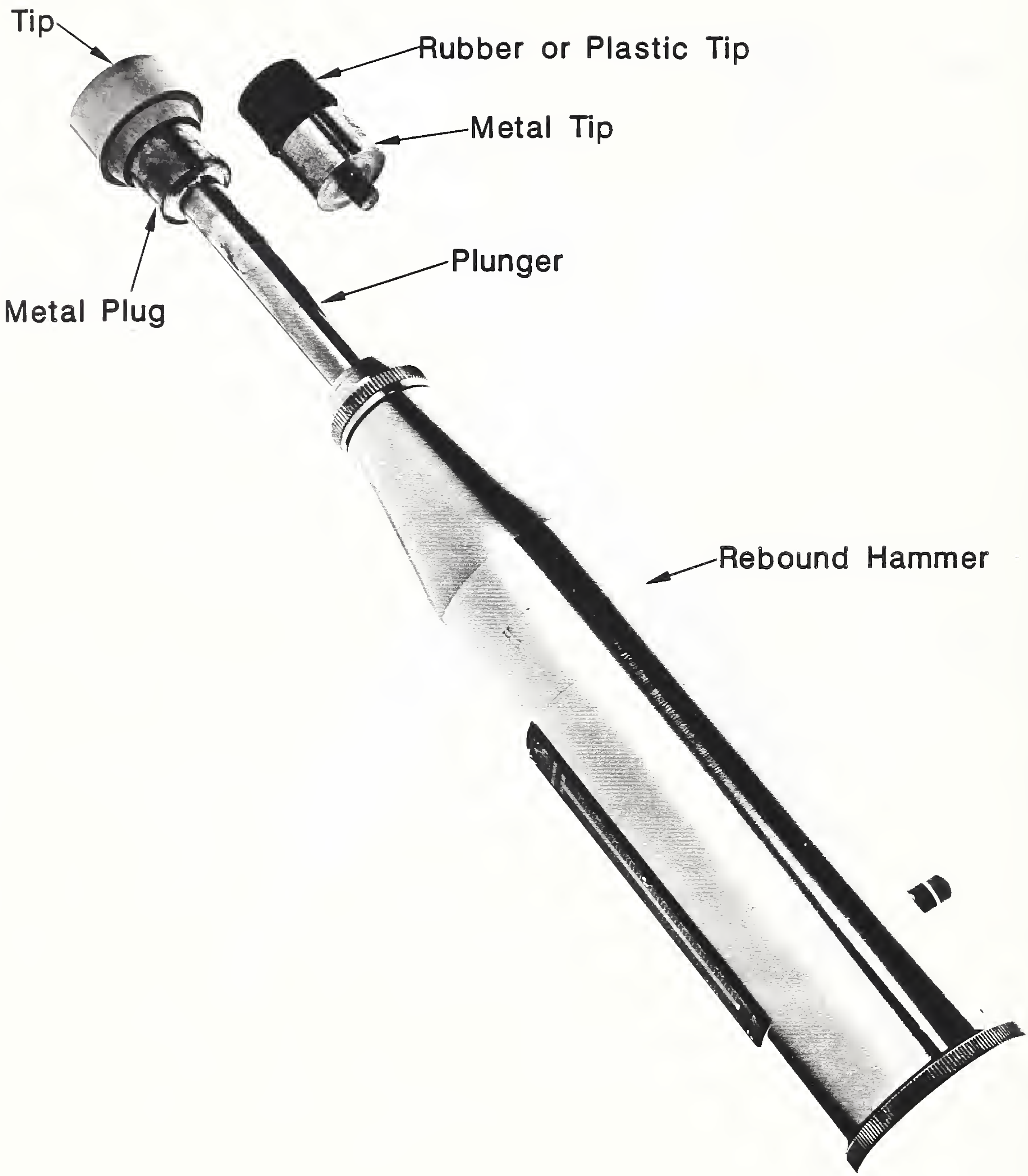

Figure A5. Prototype Device for Conducting Impact Tests

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

This report describes results of the third and final phase of a study conducted for the General Services Administration (GSA) to develop a field test method to measure the friability of spray-applied fireproofing and thermal insulation materials. Field tests were conducted on 17 fibrous and two cementitious spray-applied materials to assess surface and bulk compression/shear, indentation, abrasion, and impact properties. The tests were performed using prototype devices developed in an earlier phase of the study. As expected, the field specimens displayed varying response to dislodgment or indentation in the tests. The field tests confirmed that the goal of the study had been achieved.

In the case of the surface compression/shear test, it was found that, where comparable replicate specimens were available, variability in the test results was, in some cases, 30 percent or greater. It was also found that the use of the indentation test was limited by specimen thickness, and consequently, it was recommended that this test be omitted from testing of material friability.

It was also recommended that the surface and bulk compression-shear, abrasion, and impact tests all be used by GSA in a procedure for assessing the friable nature of spray-applied fireproofings. Assessments of friability can be performed using a systematic procedure for conducting tests as outlined in a flow diagram. A third recommendation was that, if testing is to be conducted with the intent to monitor changes in the friability of the specimens, appropriate statistical procedures should be developed.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

abrasion; asbestos-containing materials; compression; field evaluation; fireproofing; friability; impact; indentation; mechanical tests; shear; spray-applied; test devices; test methods; thermal insulations.

13. AVAILABILITY

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